A TECHNICAL INTEGRATION APPROACH FOR NASA'S DEEP SPACE HUMAN EXPLORATION PROGRAMS

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NASA is developing the capability for humans to conduct deep space exploration. The Exploration Systems Development (ESD) programs: the Space Launch System (SLS), Orion spacecraft, and Ground Systems Development and Operations (GSDO) are the first of the major systems required to support missions that push human exploration farther than ever before, including near-Earth asteroids and eventually Mars. The SLS program is developing an evolvable super-heavy-lift launch vehicle, capable of putting the necessary payloads and crew into space and on deep space trajectories. The Orion program is developing a capsule capable of sustaining and returning a crew of four from at least 21 days in deep space and will be paired with deep space habitats and other components to support long duration missions. The GSDO program provides systems required to assemble, integrate, and launch the SLS and Orion systems as well as future exploration components.

Each of these programs are large complex technical and programmatic endeavours by themselves; however, they must work as an integrated system to effectively meet NASA's goals for deep space exploration. Integration of complex systems usually requires a dedicated engineering group to integrate the system components to ensure that the delivered system will meet requirements. The traditional model for accomplishing this activity is to have an organization that operates at a level above the system components to perform Systems Engineering and Integration (SE&I) activities while the components are designed, developed and tested. ESD has assigned the SE&I activity to the Cross-program Systems Integration (CSI) office at NASA Headquarters.

This paper discusses ESD/CSI's integration model, which offers a non-traditional approach to SE&I. This paper discusses a non-traditional approach to SE&I being implemented within CSI to perform technical integration, which has required significant changes to NASA culture and governance processes. Our technical integration approach relies on integration resources already located within each program to develop necessary cross-program products as well as to represent the system perspective throughout technical development, assembly, integrated test and throughout the operational phase of the missions. The paper will discuss the management structure in place to implement this type of organization and the challenges faced in using this approach. It will also discuss how the insight and oversight of the programs is accomplished, while using program resources as well as the process required for making timely technical decisions.

I. SYSTEMS INTEGRATION AND PROGRAM ORGANIZATION

System integration is the art and science of making separate technical designs, analyses, organizations and hardware all come together to deliver a complete functioning system. Failure of good systems integration is often a contributor to major system failures, often with catastrophic results. During the early days of rocket development, NASA helped create the discipline of systems engineering to address the integration challenges presented by complex space programs, such as the Apollo program, which brought together extremely complex systems. These systems were dependent on the smallest parts of the system to work properly for the entire mission to be successful. Systems Engineering and Integration (SE&I) often relies on the use of well-defined institutional and technical processes. However, over time, SE&I processes can become onerous and dramatically increase the cost of the system while providing comparatively less benefit. Since 2011, NASA has been developing the next major human space flight capabilities and has significantly focused on affordability. This paper will describe an innovative, cost-effective approach NASA using for the critical system integration task.

Exploration Systems Development

NASA is currently developing the systems necessary to take humans into deep space. The three major programs that comprise the initial capabilities for deep space: the Space Launch System, Orion crew capsule, and Ground Systems Development and Operation. These programs are led by Exploration Systems Development Division (ESD) located at NASA Headquarters in Washington, DC, and is managed by the Deputy Associate Administrator (DAA) for Exploration Systems Development. As such, ESD is accountable to the Agency for the development, integration, and delivery of our Nation's next generation of human exploration systems for pioneering our solar system. Within ESD, NASA has organized to account for systems and programmatic integration responsibilities through the Cross-Program Systems Integration (CSI) and Programmatic and Strategic Integration (PSI) organizational entities, discussed below.

Space Launch System

The Space Launch System (SLS) program is responsible for developing the launch vehicle. This will be the most powerful rocket ever developed, initially providing at least 70t of payload to Low Earth Orbit (LEO) and 25t to cis-lunar space (Block 1 Configuration). The final configuration of the vehicle will be capable of delivering at least 130t to LEO and 40t to cis-lunar destinations (Block 2B). The Block 1 vehicle is composed of a core stage with 4 RS-25 engines, two 5-segment solid rocket boosters and an Interim Cryo-Propulsion Stage (ICPS) that is a stretched version of the Boeing Delta Cryogenic Second Stage (DCSS). The Block 2B configuration will replace the 5 segment boosters with advanced boosters and the ICPS with an Exploration Upper Stage (EUS). The first SLS upgrade is the EUS. That configuration will be called Block 1B and then the final upgrade to Block 2B will be the advanced boosters to support Mars vicinity and other deep space missions. SLS will also have a cargo variant that will be able to accommodate various payload diameters including possible 5m, 8.4m and 10m variants. The SLS program is managed from Marshall Space Flight Center (MSFC) in Huntsville, Alabama.

Orion

The Orion program is developing the Service Module (SM) and Command Module (CM) to enable deep space operations. The initial version of the CM will be capable of supporting 4 crewmembers for up to 21 days to cis-lunar space destinations. The European Space Agency (ESA) is building the SM. The initial version of the CM system will allow it to conduct re-entry from cis-lunar space at up to 11 km/s. Orion is being designed to have radiation hardened guidance, navigation and control systems that are necessary for deep space exploration. The Orion program is managed from Johnson Space Flight Center (JSC) in Houston, Texas.

Ground Systems Development & Operations

The Ground Systems Development & Operations (GSDO) program is responsible for developing the systems necessary to build, launch and recover the SLS and Orion systems. GSDO is building a Mobile Launcher capable of transporting the assembled vehicle to the launch pad, the launch pad facilities as well as modifying the previous facilities used for the Shuttle Program to accommodate assembly, integration and test of the SLS and Orion vehicles. The GSDO program is managed from the Kennedy Space Center (KSC) in Cape Canaveral, Florida.

Program Integration

Most often programs that deliver a single product (vehicle, mission, etc.) are organized as a unified program or project. Usually there is a Systems Engineering and Integration (SE&I) organization that is making sure the parts of the system will work properly as a unified whole when it is assembled. ESD however, is organized as three separate programs and, at face value, has no top-down SE&I organization. This creates a risk that programs might chose system solutions that are more beneficial to some parts of the system rather than for the overall good of the integrated vehicle. There is also a risk that individual programs could focus on delivering their individual products and sometimes that might take precedent over progress on the integrated system.

To help prevent this ESD has established the Cross-Program Systems Integration (CSI) Office and the Programmatic and Strategic Integration Office (PSI) to preform the SE&I function for the three programs. SE&I must tie the three independent programs together in a way that does not adversely impact the operations of each individual program yet keep all three programs working toward the development of a single integrated system. CSI is responsible for all technical integration of the vehicle with the ground systems, the overall architecture of the system and mission management of the various flights. PSI is responsible for integrating the programmatic activities of the three programs including, financial, schedule, configuration and risk management. Figure 1 below shows how ESD is organized.

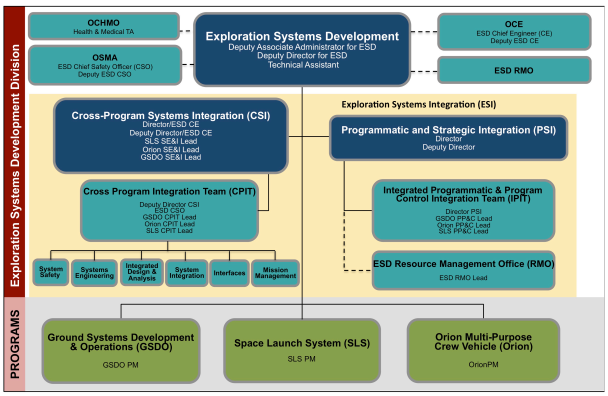

Fig. 1: Exploration Systems Development Division

This organization looks very similar to a typical program or project with the parts of a system organized by a SE&I organization. However the implementation of this organization is somewhat different than past instances of these types of organizations.

The ESD Integration Model in Context

Traditional program/project organization usually has the parts of the system and an SE&I organization reporting to a Program or Project Office, which in turn reports to a higher-level Headquarters function. Figure 2 shows the example of the prior Constellation Program, which had a typical program structure.

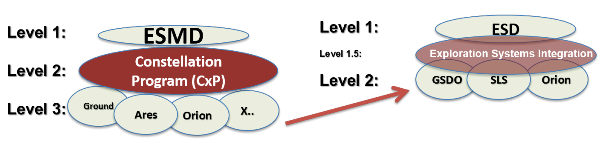

Fig. 2 Elimination of Redundant SE&I Resources

The highest-level function was the Exploration Systems Mission Directorate (ESMD), which existed at NASA Headquarters in Washington, DC and did high-level integration on policy and planning. The Constellation Program (CxP) was based at the Johnson Space Center, and within it were the projects including the Ares launch vehicle, the Orion crew capsule, ground systems, and other lunar focused projects. SE&I organizations were embedded within the CxP and within each of the projects. The budget numbers for the CxP integration workforce are shown in Table 1.

	Budget ($M)	Procurement and Travel ($M)	FTE	WYE
Cx Program Integration	190	135	359	431
ESD (PSI and CSI)	29.6	19.2	93.0	61.0
% Reduction	84%	86%	74%	86%

Table 1: Budget and workforce comparison of Constellation to ESD*

Cx program structure carried with it hundreds of civil servant full time-equivalent (FTE) and contractor work year equivalent (WYE) resources, both technical and programmatic, to manage the enterprise. Unfortunately the CxP organizational model was very inefficient as many of the problems and issues that were worked were resolved at the Level 3 Ares, Orion and Ground project levels were sometimes reworked at the CxP program level. In addition, the process to make changes to the program and project baselines was very inefficient with many actions taking months to route through the appropriate board structures.

Following the proposed cancellation of the CxP program in February 2010, the Agency looked for a more efficient way to organize the emerging human exploration programs, including SLS, Orion and GSDO programs. These programs were formally announced in August 2011, and ESD was designated at that time to lead the integration effort through CSI and PSI†. PSI and CSI serve as the integration arms of the ESD enterprise, but are not a formal program or project office. PSI and CSI have only a small number of personnel at NASA Headquarters and at the centers. However, the SLS, Orion, and GSDO programs do report to the director of ESD (see figure 1), which resembles a traditional project management structure.

The key to the ESD integration model is that the SE&I and programmatic integration workforce does not exist as a separate program office. In the new organizational model, ESD is using the program resources directly to develop integrated products,

* Source: CxP Program Manager's Recommend 2009 and ESD Program Manager's Recommend 2012. Cx Integration is estimated to have been at similar workforce levels during the 2007 SRR period as well. Cx PI and ESD perform analogous functions. ESD total includes Center-based FTEs but does not include Program FTEs and WYEs focused on integration, which may cost as much as $40-60M/yr in addition.

† In some ways, ESD can be seen as a return to the integration model of Apollo, which was likewise run out of NASA Headquarters and not out of a NASA center.

effectively eliminating an organizational layer and review process. Although ESD has some integration focused funding, the majority of resources going to the programs are based off of the programs' previously budgeted resources.

Exact calculations of the savings between ESD and Constellation Program can be difficult to achieve due to indirect cost structures at NASA. A direct but incomplete comparison can be made based upon the size of the integration budgets used by ESD and CxP. As is shown in Table 1, the ESD integration budget is around \$30M compared to the Constellation budget of \$190M. As is mentioned above, ESD does rely on program resources, which in FY13 were estimated to be around 320 FTE&WYE, with potential annual costs of around \$40-60M/yr. These resources may have been required for program development even if there was no integration function. Given both the ESD integration budget and the program SE&I contribution, we estimate cost savings for embracing the new ESD integration model are at least \$100M per year, and may be as great as \$160M per year [‡].

The ESD enterprise has greatly benefited by using this cost savings to accelerate engineering efforts and flight hardware. \$100M/yr in integration savings will have a major benefit to future human space flight affordability. From the inception of ESD in FY11 through the end of FY17, the year before the first Exploration Mission-One flight, the total integration savings would be >\$600M. The savings will be significant for a set of human space flight vehicles that are projected to support a long-term exploration campaign to the Mars vicinity.

II. CROSS-PROGRAM SYSTEMS INTEGRATION

CSI's mission is to provide technical integration across the ESD programs and to assist the ESD Deputy Associate Administrator (DAA) with effective, risk-informed decision-making to successfully achieve the Exploration Missions. CSI is responsible for all technical integration and delegates many of these functions to the individual programs. There are many elements required to work together to ensure proper technical integration. Figure 3 shows these elements. As discussed above, the majority of the workforce required to accomplish this mission is embedded in the programs. Therefore the CSI model requires very high levels of communication and organization to ensure the right items are being worked at the right time.

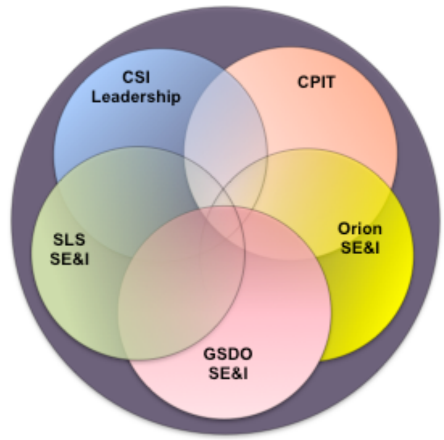

Fig. 3 Major CSI Elements

CSI Leadership

CSI leadership provides strategic objectives and guidance for necessary technical integration and integrated risk mitigation across ESD. The leadership engages with the programs, NASA Institutions, and Technical Authorities to perform effective integration across the ESD. It provides policy and direction for the integrated system. The CSI leadership reports to the ESD DAA and includes the SLS, GSDO and Orion program SE&I Leads. CSI also manages the integrated systems technical performance and integration of technical risks. The CSI management leads and the program SE&I leads communicate on a daily basis as they work daily integration problems and issues.

Program SE&I

The program SE&I leads are delegated the large majority of integrated activities and are responsible for developing the majority of integrated products for the system. Once integration activities are delegated to the program they assume ownership and are accountable for the development of these products. SLS is focused on the launch, ascent and propulsion systems. GSDO is focused on the vehicle assembly, launch readiness, and post-mission vehicle recovery and de-servicing. Orion is focused on the crew vehicle, flight systems, and crew systems. The flow of these responsibilities is reflected in the leadership of various parts of the CSI organization.

[‡] We have cross-checked this estimate based upon a comparison of the total number of equivalent persons doing integration collectively between CxP and ESD at all levels (1-4). In total, there is a several hundred-person decrease in the total SE&I workforce at all levels, which validates the conservative \$100M per year savings estimate made above. However, a direct comparison of the integration budgets may be the more accurate way to measure savings, because the program integration personnel may have been required costs even without an integration function. This would yield \$160M per year in savings, as shown in Table 1.

Cross-Program Integration Team

The Cross-Program Integration Team (CPIT) serves as the backbone for technical integration across the Enterprise, using product-oriented Integration Task Teams (ITTs) across six key functional areas: System Safety, System Engineering, Integrated Design & Analysis, System Integration, Interfaces and Mission Management. ITTs are organized as shown in Figure 4. As discussed above, the teams are comprised primarily of program resources. Each team is usually composed of an ESD CSI representative (rep) or a program rep.

CPIT Leadership

The CPIT leadership team comprise technical integration leads from ESD, SLS, Orion, and GSDO. Their primary responsibility is to make sure the best-integrated system solution is reached. They report to CSI management. The CPIT leadership provides daily guidance and direction for the integrated system. They provide direction for the functional areas and to the ITT's, and maintains the business rhythm for technical integration. They are responsible for forming ITT's and other teams as needed. The CPIT identifies and maintains top integrated technical issues and risks. The CPIT leadership monitors the progress of the team, and ensures they are delivering products on schedule. When necessary they proposed changes to the teams when those teams are not performing adequately.

Functional Areas

There are six functional areas, each with a designated leader from ESD, SLS, Orion, or GSDO, as described below.

System Safety ensures that the integrated system is safe, understanding the integrated system's failure modes, hazards/controls and technical risks.

System Engineering manages the overall technical baseline for the integrated system ensuring enterprise Verification and Validation (V&V), flight certification approach how necessary data/information is integrated across the Enterprise and human requirements and overall health and medical objectives are met.

Integrated Design and Analysis provides design requirements and predicts system performance and environments by analyses and tests. It covers strategies for aborts, ascent and end-to-end mission performance, develops the integrated loads and environments for the system and maintains the physical configuration of the integrated system.

System Integration assembles and tests the integrated system to ensure that it's ready to fly. It is responsible for the integrated approach to avionics and software across the three programs, developing integrated test and checkout objectives for testing plans,

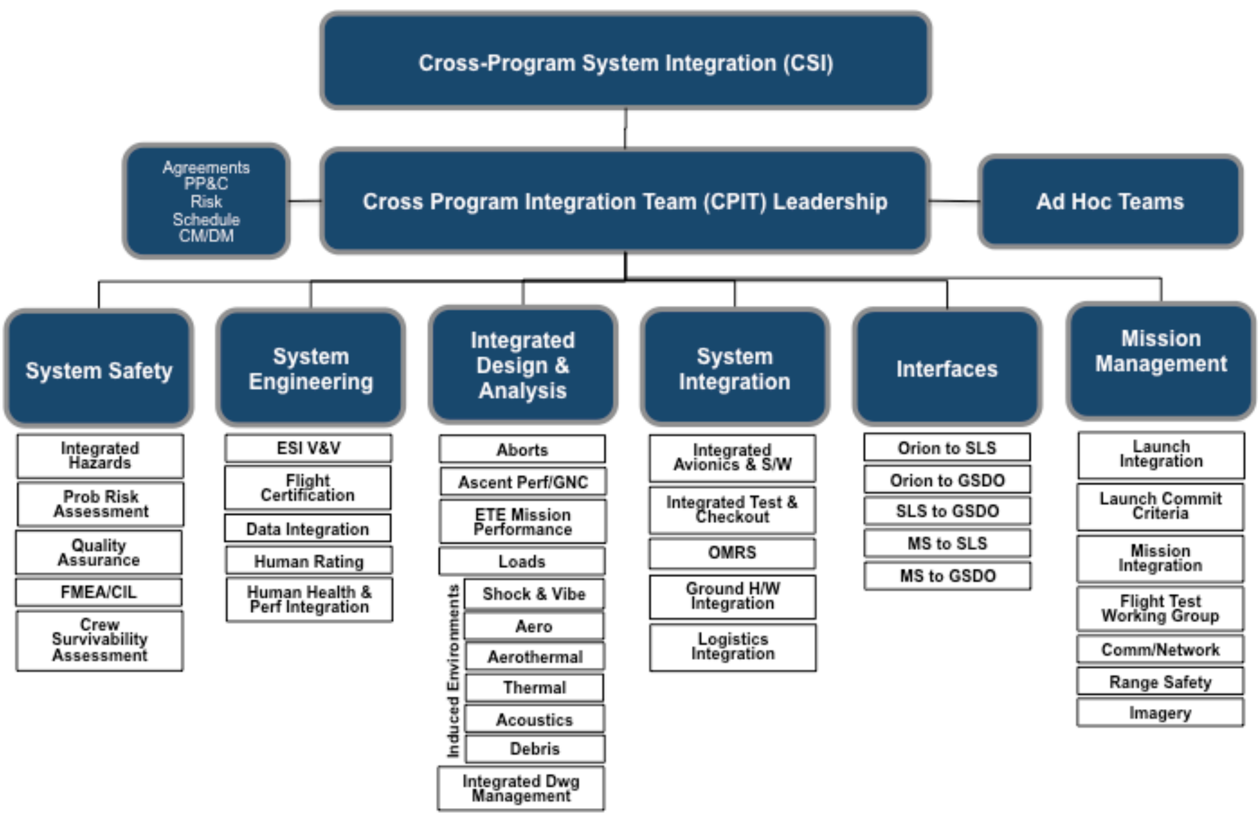

Fig. 4 CSI Organization

operations and maintenance requirements at the launch site. It also coordinates ground hardware integration activities and develops the integrated logistics strategy for the enterprise.

Interfaces develops and integrates Interface Requirements Documents (IRDs) and Interface Configuration Documents (ICDs) and tracks required data deliverables between programs related to these IRDs/ICDs

Mission Management develops and defines integrated systems and plans required to operate the system through mission completion. This includes development of common guidelines and philosophy across the Programs for launch countdown operations and launch planning, developing Launch Commit Criteria and coordination of day-of-launch products, developing the mission requirements and the process/products associated with mission definition and execution. Mission management also develops Flight Test Objectives (FTO's), overall technical communication and network strategy, imagery requirements and interfaces with the launch range.

Functional Area Leads

For each area, a Functional Area Lead (FAL) reports to CSI leads each Functional Area. The FAL is a leadership position that influences and coordinates program resources that are provided to support the integrated product development. In a sense, they are an extension of the CPIT leadership however they have more of an 'influencer' role. Their primary responsibility is to build relationships with the ITT's and Program and Center management supplying the resources to influence the development process. They are responsible for leadership and insight, not oversight or control. They are aware of integrated issues within their own functional areas so they can ensure vertical integration in their areas. They also need to be cognizant of tasks in other functional areas to make sure ITTs are integrating horizontally across the CSI organization. They assure that all tasks worked in their area are to an appropriate level of quality. They actively review team membership and make recommendations. They identify tasks to be added or deleted in functional area and propose options to the CPIT leadership. FAL's also develop and maintain a summary schedule with the ITT leads for their functional area. They resolve issues among ITTs within their area and set priorities and provide advocacy for resources for ITTs. They report to the CPIT leadership team on a regular basis via a weekly meeting and daily tags to raise potential issues.

Integration Task Teams

ITTs are responsible for producing and managing all cross-program technical integration products and analyses. ITTs are product-focused and each ITT must have at least one integrated product. All ITT developed products are approved through the governance process (discussed below). The governance process board structure is integrated in nature and comprises leadership from CSI and the programs. Each ITT develops a task agreement defining scope, approach, membership, products and schedule for the ITT. This is worked with the FAL and is signed and approved by the CPIT, verifying the need for the product and how it is to be developed. ITT's are led and staffed by subject matter experts from ESD and/or the Programs. Programs are assigned the lead for ITT's based on the how the delegation of responsibilities has been made. Generally these are along the lines of the strengths of the team. For example, SLS has the lead role in developing integrated loads and induced environments for CSI. This makes sense as they are the center of activity for the launch vehicle and are primarily responsible for ascent. Orion has the lead role for Mission Integration. Figure 5 show the overall leadership roles programs hold in CSI. This is identical to Figure 4 but has boxes colored to reflect which program has the primary responsibility.

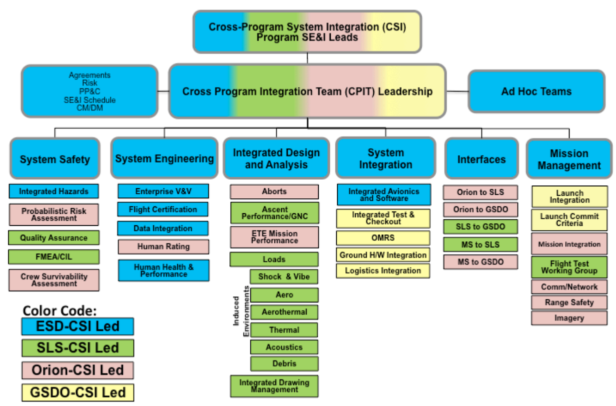

Fig. 5 CSI Organizational Leadership

ITTs are responsible for Cross Program Integration within team and across to other teams, as required. They bring recommendations to CPIT in coordination with their FAL for integrated products and elevate issues to CPIT leadership when required.

ITT Leads

ITT leads are assigned by the Programs and/or ESD (see figure 5) and are responsible for ensuring that the integrated product represents the best system level solution. The ITT lead must also make sure that the individual programs input is represented and bring forward minority opinions when presented. They must be strong, confident technical leaders because their responsibility to provide integrated solutions may put them at odds with their own or another program's desires. They are responsible for delivering the integrated products on schedule and to the appropriate scope. ITT Leads develop and maintain task agreements that define scope, approach, team membership and schedule for product development. The ITT lead ensures that team members have an equal voice; manages concurrence and dissent, and makes sure all program positions are considered. Sometimes this requires them to elevate issues to the FAL or CPIT leadership to help the team move forward. The ITT lead should do this relatively quickly to assure the team does not stall and miss necessary program deadlines. ITT leads develop and maintain detailed schedules for products their team produces and coordinates these schedules with the FAL to report to CSI and program management. When issues arise with deliver the ITT lead works resource and schedule issues with the FAL and program management to resolve the issue.

ITT Membership

ITT members, usually called Program Reps must coordinate and clearly articulate their program's positions, contribute to discussions to arrive at the best system solution, and be able to understand and articulate any differences if/where they exist. They are to vet ITT ideas and products with their programs to ensure that the system level products being developed will work well with the individual program plans. When that is not the case, they will work with ITT and CPIT leadership to develop an alternative that provides the best system level solution. Program representatives are to convey the ITT positions to their program and program position to the ITT, and work to develop an integrated solution.

Ad-hoc Working Groups

CPIT uses ad-hoc working groups or tiger teams to perform cross program technical activities that are short lived in nature or only need to be updated on a periodic basis. Sometimes these teams may not line up with a particular ITT or functional area. These teams generally exist to develop a product or perform a function and then they are disbanded. These teams are established and approved by CPIT leadership. They usually do not have a Task Agreement developed but rather are informally directed as to the nature of the task.

Integrated Product List

The IPL captures all products generated by the ITT's and Working Groups. The IPL is owned and managed by the CPIT leadership with Configuration Management (CM) support from PSI. Products are added and deleted based on the CPIT's determination that the product is needed for the integrated system. The IPL is a data managed list of these products. The IPL tracks the integrated products, the Organization of Primary Responsibility (OPR) and the authoritative board that is responsible for approving the product. The OPR is usually the organization with the lion's share of the work, with the most need/interest in the product. Typically this is the organization that has the lead of the ITT developing the product. The OPR determines which program's CM system the product is maintained within. The IPL is linked to the locations within the programs and ESD CM systems to allow the team to quickly access the latest approved version of these products.

Governance

The goal is to make the "decision velocity", the speed at which a problem can be worked and a solution decided upon, as quickly as possible[§]. ESD deliberately emphasized decision velocity when it established the governance and technical integration approach in 2011. The sharing of workforce and removing a layer of organization that existed in Constellation was previously discussed. This change in workforce also requires a change in governance approaches in order to accelerate decisions. Previous organizational models layered decision boards creating a process that sometimes took many months for a formal decision to be made. Taking that lesson learned from these programs the intent is to make the decision process as "flat" as possible with as few boards as possible. One of the ways to accomplish this is to combine boards such that all the necessary parties hear the same issue once. Figure 6 depicts the board structure for integrated products.

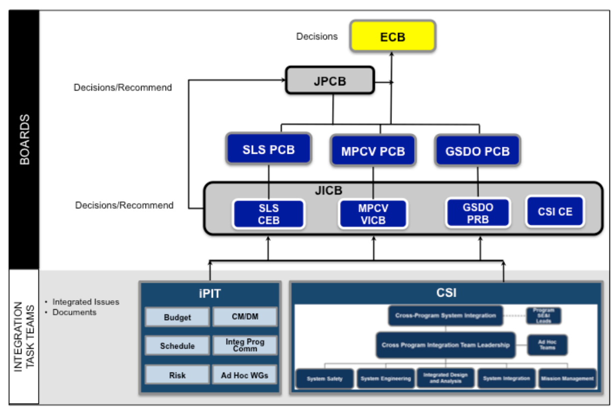

Fig. 6 ESD Governance Structure

Essentially all integrated products on the IPL are approved at the Joint Integrated Control Board (JICB). Products are developed by the ITT and they are reviewed and approved by the program that is the OPR for the product. That part of the review is held as a JICB. Each program as well as CSI, joins the meeting and declares they have a quorum and is ready to review

[§] Correcting a bad decision, especially during program formulation, can often be much less costly than delaying to make any decision whatsoever.

the integrated product. Usually once the product is approved at the JICB it is complete. However, if the product led to cost or schedule impacts beyond the authority granted to the program boards approving it, then the product is taken to the Joint Program Control Board (JPCB) where the program managers for all three programs work out the appropriate method for accommodating the product. If the programs do not have the authority to approve the change, usually due to large expenditures or sometimes disagreement among program leaders at the JICB or JPCB level, then the matter is taken to the ESD Control Board (ECB). Occasionally the JPCB is bypassed if all parties recognize that the JPCB will not be able to resolve the issue. Also, there are some CSI products on the IPL that require approval at the ECB (e.g., ESD Systems Engineering Management Plan (SEMP)) that go straight from the JICB to the ECB. While this seems like several layers of boards that each product must traverse, in reality, very few products go to the JPCB and even fewer go to the ECB, unless that is the approval body for that particular product. The vast majority of items go through the JICB and that is their last review, essentially creating a board structure that is one level deep. The only other time items may be raised to a higher board level is when there is disagreement at the JICB or JPCB on the resolution of a particular topic. This has only happened two times in the two years this architecture has been in place

Managing Cross-Program Agreements and Interdependencies

A key part of integrating three major programs is having a good methodology for managing cross-program agreements. The approach taken to managing the items that must be exchanged across program boundaries has evolved since ESD first began. Initially there were two methods. The first began organically with the use of Excel spread sheets to track items (interdependencies) that needed to be developed and delivered from one program to another. The spread sheet contained scope and content of the item and its need date by one program and the delivery date that could be delivered by the other program. When items were of sufficient importance, the programs would use formal agreements such as a Bilateral Exchange Agreement (BEA's) or a Memorandums of Agreement (MOA's) to get program manager recognition of the necessary deliverable and date. Usually this involved the delivery of key hardware to another program (flight hardware, pathfinders for V&V, test articles, etc.) or key software or emulators used for testing to another program. Also these may include certain specific data deliveries that are essential inputs into analyses/activities on program critical path (example – Mass properties, FEMs, Critical Math Models feeding a DAC). Over time this has resulted in numerous BEA's and MOU's, among other types of written agreements as well as numerous items being tracked in the spread sheet. This approach to tracking interdependencies was acceptable during formulation of the ESD programs, but the intensity and urgency of tracking interdependencies is expected to increase as programs undergo testing and integration.

To improve its interdependency management, CPIT leadership recently named an Agreements Manager to consolidate these agreements into documents that can be managed and tracked at the CSI level. The Agreements Manager leads a team to negotiate and resolve agreements and interdependencies between programs regarding scope or schedule for necessary data, hardware or software products. The Agreements Manager also ensures the negotiated agreement is folded into the affected program's technical and schedule baseline and is managed to completion by the CPIT or a Program.

Communications

Clear communication is critical in any SE&I organization. ESD's model requires a heightened level of communication to assure that proper communication of program and integrated issues is occurring. To that end the ESD, CSI, PSI the Program SE&I leads, the CPIT leadership, FAL's, ITTs have numerous meetings and tag-ups to enhance communication. The CPIT leadership meets at the start of each business day with a 30-minute tag-up. The FAL's participate but the primary focus is to raise upcoming technical issues. Every Monday the CPIT leadership, FAL's and ITT's review the integrated systems progress, reviewing technical performance measures, schedule status, top issues, functional area accomplishments and reviewing special topics. Every Tuesday CSI meets with the Office of the Chief Engineer (OCE) to status hot topics or items of interest. The CPIT also holds a meeting for the CPIT leadership and the FAL's where FAL's can speak candidly about sensitive topics and issues they are facing. That meeting is unstructured and an open forum for the FAL's to seek advice, guidance or resolution on difficult issues. Every week each FAL meets with their ITT leads to discuss progress, issues and concerns. Every Friday afternoon CSI management, CPIT leadership and the program SE&I leads meet to discuss top issues for the week. The CPIT leadership and FAL's meet to discuss the cross-program risks and develop the overall risk posture for the integrated system. CPIT leadership and the FALs also prepare and present a monthly status report to ESD management. Special meetings are often scheduled during the week to handle special topics that do not fit in any of the time slots above. Typically there are one or two meetings a week for these types of issues.

The CPIT leadership and FALs usually meet for a face-to-face at one of the centers every quarter. The CSI Director and Deputy Director usually travel to each of the three main centers (KSC, JSC, and MSFC) once a month and use the opportunity to meet with the CPIT leads, FAL's or ITT leads stationed at the centers they are visiting. The CPIT leadership team also conducts an annual "roadshow" to remind ITT and program members the role CPIT plays in developing the integrated system as well as to update the teams on changes to the organizational model.

The ESD, PSI, CSI and the CPIT also each maintain wiki's to enhance communication with the entire team. Organization, team rosters, task agreements, links to integrated products, risks, hazards and other critical cross-program information is on the wiki as well as links to program wiki's. Many ITT's also have wikis/portals, which are accessible from the CPIT wiki.

Technical Authority

The Director of CSI is the Chief Engineer for ESD and the Deputy Director is the Deputy Chief Engineer for ESD. They are matrixed to support the ESD DAA but they are formally part of the NASA technical authority command chain and report though that chain of command. Technical Authority is a decision structure documented in NPR 7120.5D, and was adopted to support safety and mission success. The concept is consistent with the NASA Governance Model and implements recommendation from the Columbia Accident Investigation Board (CAIB). Specifically, the CAIB recommended the establishment of an independent Technical Engineering Authority that is responsible for technical requirements and all waivers to them and will build a disciplined, systematic approach to identifying, analysing, and controlling hazards.

CSI management exercises that duty as part of their daily work managing the integrated systems development. They determine if the programs are meeting engineering standards, conducting sufficient Independent V&V (IV&V) and initiate their own Independent V&V activities, as they deem necessary. They are engaged with independent reviews such as those conducted by the NASA Advisory Council (NAC) and the Aerospace Safety and Advisory Panel (ASAP), both of which report to the NASA Administrator, and the Standing Review Board that conducts independent reviews of the Programs and ESD.

CSI monitors technical progress via periodic assessment and through program and integrated Technical Performance Measures (TPMs)

III. ADVANTAGES AND CHALLENGES

Our approach to integration has some advantages as well as some challenges that must be dealt with for deep space exploration to be successful. The cost savings discussed above are an obvious benefit. However, the most important improvements may be related to efficiencies and other efforts to encourage an integrated system perspective. The ESD integration model has forced CSI and the programs to concentrate on improved communication, as discussed above. The programs and ESD are motivated to enable quick decision-making and have created joint boards to eliminate redundant meetings and delays in decision making. The high level of communications helps move problems, once identified, to a board decision quickly. Having the program SE&I and CPIT leads as part of the CSI/CPIT management team puts responsibility for solving system problems on the programs as well as CSI. The overall effect is a team approach to resolving the inevitable integration challenges that will occur in an enterprise of this size.

There are always challenges to overcome in any organization model. This model is no exception. One of the most troubling issues to work with stemmed from lingering effects of the culture and attitudes that formed while the Constellation Program was active. During CxP, the vehicle elements struggled with issues stemming from redundant SE&I resources, overly detailed requirements, and a highly process oriented governance system. This led to team delays and extra costs, which some believed contributed to the cancellation of CxP. When the new ESD programs were formed as independent entities/programs, many wanted to prevent CxP's excesses in systems engineering in the new programs. Many in the programs felt that the programs could "self-integrate" to deliver a complete system. While there is some truth to the fact that element providers can see the needs of the larger system and provide potential solutions it, the chances of missing systems level issues are higher. It is generally not the case that an individual element of the system will have a complete systems perspective or have enough knowledge of the other parts of the system to propose solutions or even see when potential issues might arise. Building a new rocket system, especially one that is the largest the world has ever seen, is fraught with potential issues, any one of which can lead to disastrous consequences. While it is probably true that CxP was too extreme in many areas it is also probably true that SE&I cannot be adequately accomplished by the parts of the system alone.

The ESD integration model has a defined process and forums that help ensure a system perspective in integration. The culture at the programs and at ESD has changed significantly to embrace the need for handling holistic systems integration. CSI has grown and evolved from having almost no system engagement at the beginning to the current model as discussed in this paper. The model has been functioning for a little over a year and has led to a significant culture change, with the need for a systems focusing being embraced within some low-level task teams. There are still pockets of element/program-only thinking but this is quickly changing as the ESD programs are moving to testing and manufacturing phases of development where higher levels of cooperation and integration are necessary.

However, decision velocity still can be impacted from these program centric attitudes. ITTs are intended to provide the best systems solution however they are made up of members from the programs. Sometimes the ITT progress stalls because the program reps are unwilling to budge off the program position in lieu of the best system solution. Other times the team may be driven to consensus mode, with the consequence being a recommendation that is the least painful to all the programs. These challenges are addressed with constant reinforcement of the responsibilities the ITT leads and members have to represent the program view but champion the best system solution. If the team is truly in a disagreement they are encouraged to bring the issue to CPIT leadership as soon as possible for guidance and possible elevation to the JICB for a decision.

Another integration challenge is keeping these programs appropriately connected on programmatics, or cost and schedule issues. CSI and the Programmatic and Strategic Integration (PSI) office (mentioned above) work jointly to try to handle these programmatic challenges. For example, sometimes funding profiles or schedules for one program is not directly compatible with another's funding profiles and schedules. These disconnects must be actively managed. The Agreements Manager and the interdependencies process is one way to do this. Developing integrated schedules and combining the program and CSI SE&I schedules are key in addressing these issues. Another challenge is developing and managing integrated risks. Programs typically have different perceptions of the same risk and often risk mitigation plans that are different as well. CSI and PSI work with the programs to develop an integrated risk approach that allows the programs to own their parts of the risks while still owning them and working the integrated risk mitigations at the ESD/CSI level. Technical integration can only succeed if programmatic integration succeeds as well, and ESD/CSI/PSI take this burden seriously.

III. SUMMARY AND CONCLUSION

NASA is developing a new deep space capability through a new model for integration. The systems necessary for exploration are complex and unforgiving: good SE&I is necessary to assure successful and safe development, assembly, testing and operations. The ESD/CSI integration model is leaner and more efficient than recent SE&I efforts in human space flight. High levels of communication between the program SE&I and CSI allows for this approach to be successful. The new model also employs significantly streamlined decision-making process and governance model. As discussed in the paper the potential cost avoidance is at least over $100M a year. However, the benefits are likely much greater. Strong communication is helping to increase rigor in the decision-making process. Further, having element/program-level experts engaged in generating system-level solutions is likely saving much more as decisions are made quickly. The ESD/CSI integration approach has streamlined required resources and processes to obtain approval for every major system product and decision. The integrated system has been progressing on schedule for the past two years.

Evidence for the success of this integration model is strengthening. At the time of writing, the programs have all completed their technical Preliminary Design Reviews (PDRs) with no major issues (Orion is in process of its programmatic portion of their PDR). This is a major accomplishment in terms of progress for the new ESD programs. CSI continues working the integration process. An ESD-level integrated system review will be held at the beginning of 2015. While there are still challenges implementing the integration model, it should be recognized that every system or organization has challenges and unique issues that occur regardless of how the program is managed.

A key factor for success, no matter what organizational model you use, is the people leading the effort. This model is no different. It depends on people with the right personalities, blended with practical experience and expertise, willing to give and take with the ultimate goal of optimizing for the total system. These integrators must be knowledgeable of the programs' designs and technical issues. They must be willing to make decisions at the right times. They must take ownership of the integrated system. The CSI management, Program SE&I leads, CPIT leadership, the FALs and ITT leads all exhibit those characteristics and their team approach will make this endeavor successful.

Through people, the ESD integration model may yield its most long lasting benefits. This new culture of integration can carry technical and programmatic rigor into future developments. NASA culture is changing in the ways needed to explore deep space. The success of the ESD programs will be another sign that NASA is evolving along with the rest of the space industry. As space enthusiasts are excited about the emerging 'New Space' movement, so too should they look forward to and encourage the emergence of a 'New NASA' as well.